APPENDIX C

BMP NUTRIENT REDUCTION CALCULATIONS

Onsite Wastewater Disposal System (OWTDS) BMP Calculations

In order to determine the nutrient loading by OWTDS to groundwater, local watershed data and knowledge has been utilized.

Twelve OWTDS existing near Red Mill Pond in Lewes, Delaware were monitored in 1993 (DNREC, 1994). The average total phosphorus concentration of the effluent from these systems was 15.7 mg/L, while the total kjeldahl nitrogen (TKN) concentration was 58.5 mg/L and the nitrate/nitrite concentration was 0.8 mg/L. The total nitrogen concentration of the average effluent from this study was summed to equal 59.3 mg/L. Conversations with professionals in this industry have suggested that 50.0 mg/L is a more appropriate value of TN concentrations in on-site effluent and this value has been used in subsequent calculations.

Small systems, which are typical individual household systems, have flows less than 2,500 gpd. The average design flow for individual residential OWTDS is 221 gpd.

The nutrient load to the watershed from drain fields can be established by determining the product of the above concentrations and respective flow rates.

Robertson and Hartman (1999) found that 85% of the total phosphorous in the effluent will be retained in the vadose zone or the unsaturated soil above the water table, most of which is within 12 inches of the drain field (Gold and Sims, 2000). Initial calculations presented by the Department, also based on the Red Mill Pond study, assumed that 87% of TP and 52% of TN is assimilated in the soils once the effluent leaves the septic tank.

The final loading rates from OWTDS to groundwater can be determined using the following equations:

Small systems (<2,500 gpd):
[Conc. (mg/l) x (lb/453,592 mg)] x [(221 gal/system/day) x (3.7854 l/gal)] x (1-soil assimilative capacity)

Thus, the OWTDS nutrient loading rates to groundwater in the Christina Basin Watersheds are:

- 0.052 lbs TN/system/day and 0.004 lbs TP/system/day for individual small systems less than 2,500 gpd

I. Connecting OWTDS to Sewer Districts

According to the New Castle County Department of Special Services records of sewer agreements, in New Castle County there was an average of 32 systems per year eliminated and connected to the public sewer. These estimates are determined from the records of sewer agreements for 2004, 2005 and 2006.

Reductions for systems that are connected to plants receive a 100% efficiency since nutrients remain in the ecosystem (DNREC Groundwater Discharges Section, personal communication, 2003). The nutrient load reductions are calculated using the following equation.

Nutrient load reduction (lbs/day)	=	OWTDS loading rate (lbs/system/day)	x	# of eliminated OWTDS	x	Reduction efficiency

EX: TN reduction due to OWTDS connection:

TN load reduction (lbs/day)	=	0.052 lbs TN/system/ day	x	32 eliminated OWTDS	x	100%	=	**1.68 lbs TN/day**

II. <u>OWTDS Pump-outs</u>

Using a GIS, an analysis was conducted that determined as of 2011, there were 7,859 OWTDS in the Christina Basin including 6,010 septic systems and 1,849 cesspools.

Due to regulations in place in the Christina Basin, estimates were made that 1/3 of the septic systems are being pumped out a year based on a 1,000 gallon tank capacity. By assuming that after three years, a septic tank will contain 750 gallons of effluent and 250 gallons of septage (volumes based on local inspector-hauler observations), and using the concentrations of effluent and septage given above, the effluent load reductions per system achieved by a pump-out program are shown below in Table 1.

Table 1. Nutrient Reductions from an OWTDS Pump-Out

	Total N (lbs/system/pump-out)	Total P (lbs/system/pump-out)
OWTDS Effluent	0.31	0.10
OWTDS Septage	1.25	0.52
Total	1.56	0.62

<u>Effluent:</u>
Nutrients Removed (lbs/system/pump-out) =
Conc. (mg/l) x (lb/453,592 mg) x (750 gal/system) x (3.7854 l/gal)
<u>Septage:</u>
Nutrients Removed (lbs/system/pump-out) =
Conc. (mg/l) x (lb/453,592 mg) x (250 gal/system) x (3.7854 l/gal)

The load reduction in the water column achieved by this practice can be calculated using the following equation.

$$\text{Nutrient load reduction (lbs/yr)} = \text{Reduction rate (lbs/system/pump-out)} \times \left[\text{\# of existing OWTDS} \times \frac{\text{1 pump-out}}{\text{3 years}} \right]$$

EX: TN reduction due to OWTDS pump-out program:

$$\text{TN load reduction (lbs/yr)} = \text{1.56 lbs TN/system/pump-out} \times \left[\text{6,010 existing OWTDS} \times \frac{\text{1 pump-out}}{\text{3 years}} \right] = \textbf{3,125.2 lbs TN/year or 8.56 lbs TN/day}$$

III. <u>OWTDS Performance Standards</u>

Wastewater pretreatment technologies exist to remove nitrogen, phosphorus, or both from wastewater prior to soil dispersal of the effluent. A consultant hired by the Department evaluated the performance efficiencies of these technologies then recommended performance standards for OWTDS in Delaware and several levels of performance efficiencies for nitrogen and phosphorus (The On-Site Wastewater Corporation, draft written communication, 2003).

A recommendation in the Christina Basin Pollution Control Strategy surrounding small septic systems requires new and replacement subdivisions in areas outside of sewer districts to be equipped with systems that can reach standards such as "Performance Standard Nitrogen 3" (PSN3) to reduce nutrients. Technologies that can achieve PSN3 will produce a 50% reduction of effluent TN concentration when compared to the TN influent concentration. The nutrient load reduction can be determined using the following equation.

$$\text{Nutrient load reduction (lbs/day)} = \text{OWTDS loading rate (lbs/system/day)} \times \text{\# of existing OWTDS in program} \times \text{Reduction efficiency}$$

EX: TN reduction due to upgrading to alternative systems:

$$\text{TN load reduction (lbs/day)} = \text{0.052 lbs TN/system/day} \times \text{6,010 OWTDS} \times 50\% = \textbf{157.42 lbs TN/day}$$

IV. Connecting Cesspools to Sewer Districts

Reductions for cesspools that are connected to sewer. The nutrient load reductions are calculated using the following equation.

Nutrient load reduction (lbs/day)	=	OWTDS loading rate (lbs/system/day)	x	# of eliminated OWTDS	x	Reduction efficiency

EX: TN reduction due to OWTDS connection:

TN load reduction (lbs/day)	=	0.052 lbs TN/system/ day	x	32 eliminated OWTDS	x	100%	=	**1.68 lbs TN/day**

Stormwater BMP Calculations

I. Stormwater BMPs

Several types of structures that treat stormwater runoff are used throughout the Christina Basin. The efficiencies associated with common stormwater BMPs are listed in Table 2. In order to calculate the load reduction to the receiving water body, the calculation outlined below is used.

Table 2. Stormwater BMP Reduction Efficiencies (Chesapeake Bay Program)

BMP	TN (%)	TP (%)
Wet ponds	30	50
Dry pond	30	20
Infiltration	50	70
Biofiltration	50	70
Filtering Practice	40	60

Nutrient load reduction (lbs/day)	=	Total drainage area treated by structures (acres)	x	Urban loading rate (lbs/acre/yr)	x	Reduction efficiency

EX: TN reduction due to wet ponds in the Brandywine:

TN load reduction (lbs/day)	=	244 acres treated	x	8.94 lbs TN/acre/yr	x	30%	=	**654.59 lbs TN/yr or 1.79 lbs TN/day**

II. Potential Future Stormwater Retrofit Projects:

It is anticipated that 30% of current stormwater BMP drainage acres will need to be retrofitted which comes out to be 149 acres in the Brandywine watershed, 2,167 acres in the Christina watershed, 552 acres in the Red Clay watershed and 1,826 acres in the White Clay watershed that will be retrofitted in the future. It is difficult to project, however, the exact number and type of treatment structures that will be used. The majority of stormwater practices currently in use in the watershed are wet and dry ponds, while infiltration, biofiltration, and filtration structures together are less likely to be used. It is unlikely that these same proportions will be used in future retrofit projects since the construction of ponds will require a considerable amount of space and it may be unfeasible to create these structures in areas that are already developed. Because of this, it has been assumed that future retrofits will be more equitable with equal implementation of ponds and other practices.

The load reductions achieved from the stormwater BMPs currently on the ground have been summed into two categories, “Ponds” and “Other.” These values were divided by the total area treated in each category to calculate nutrient reduction rates as follows in Table 3:

Table 3. Nutrient Reduction Rates for Future Stormwater Retrofits				
Watershed	**TN Reduction Rate Ponds**	**TP Reduction Rate Ponds**	**TN Reduction Rate Other BMPs**	**TP Reduction Rate Other BMPs**
Brandywine	0.0074	0.0006	0.0114	0.0011
Christina	0.0027	0.0003	0.0043	0.0007
Red Clay	0.0052	0.0004	0.0087	0.0010
White Clay	0.0062	0.0003	0.0104	0.0008

The potential future loading reduction to the stream as a result of retrofitting the aforementioned acres of lands can thus be determined using the equation below.

Nutrient load reduction (lbs/day) = Reduction rate (lbs/acre/day) x Acres of retrofit x Future percent use of practice

EX: TN reduction from future stormwater ponds in Red Clay watershed:

TN load reduction (lbs/day) = 0.0052 lbs TN/acre/day x 1,825.77 acres x 30% = **2.84 lbs TN/day**

Open Space Calculations

I. Grassed Open Space

Grassed open space as protected during the development process is treated as a land use change from its original state usually either agricultural cropland or forestland to grassed open space. Thus, the acres that undergo change will receive a lower loading rate. The loading reduction is calculated as follows.

$$\boxed{\begin{array}{c}\text{Nutrient load}\\\text{reduction}\\\text{(lb/day)}\end{array}} = \left[\boxed{\begin{array}{c}\text{Original}\\\text{loading rate}\\\text{(lbs/acre/day)}\end{array}} - \boxed{\begin{array}{c}\text{Grass loading}\\\text{rate}\\\text{(lbs/acre/day)}\end{array}}\right] \times \boxed{\begin{array}{c}\text{Acres of open}\\\text{space}\\\text{practices}\end{array}}$$

EX: TN reduction due to open space provisions in the UDC in the Christina watershed:

$$\boxed{\begin{array}{c}\text{TN load}\\\text{reduction}\\\text{(lb/day)}\end{array}} = \left[\boxed{\begin{array}{c}\text{0.019 lbs}\\\text{TN/acre/day}\end{array}} - \boxed{\begin{array}{c}\text{0.017 lbs}\\\text{TN/acre/day}\end{array}}\right] \times \boxed{\begin{array}{c}\text{2,500}\\\text{acres}\end{array}} = \boxed{\textbf{4.25 lbs TN/day}}$$

Agriculture BMP Calculations

The following calculations are provided as a result of the Agricultural Pollution Control Strategy Workgroup's efforts in gathering the best available science for nonpoint source pollution prevention from agricultural sources. The workgroup began meeting in April 2002 to gather the best available data on nutrient efficiencies for various agricultural best management practices. These recommendations and calculations are based on averages over several years from different studies and are dependent on weather conditions, soil type, crop production intensity, excess manure generation, topography and other site specific conditions. In addition, a lag time likely exists between practice implementation and benefit observation, which can not currently be estimated since all nutrient fate and transport processes are not well understood at this time.

I. Cover Crops

Nitrogen reduction efficiencies for cover crops were calculated using a weighted average method for each year. The data used in this calculation came from ranges of cover crop TN efficiencies for several plant species presented by J.T Sims and J.L. Campagnini (written communication, 2002). The Workgroup chose a single efficiency, often an average of the range, for the commonly used species in Delaware (Table 4). This information was used to calculate an average efficiency of the crops planted in the Christina Basin which is determined to be 55% for the 2010-2011 season as wheat was the primary crop used. It should be noted that with this approach, the efficiency will change from year to year, depending on the acreage of each cover crop species planted. For TP, the Workgroup referred to the best professional judgment presented by Sims and Campagnini, which was "less than 5%," and will be considered for these purposes as 4.9%. The nutrient load reduction is calculated with the equation shown below.

Table 4. Cover Crop Efficiencies for TN

Cover Crop Species	Work Group BMP Efficiency (%)
Barley	70
Hairy Vetch	6
Annual Rye	65
Cereal Rye	54.5
Oats	55
Wheat	55

$$\text{Nutrient load reduction (lbs/day)} = \text{Agricultural loading rate (lbs/acre/day)} \times \text{Acres of cover crops} \times \text{Reduction efficiency (\%)}$$

EX: TN reduction due to 7.30 acres of cover crops in the White Clay watershed:

$$\text{TN Load Reduction (lbs/day)} = \text{0.019 lbs TN/acre/day} \times \text{7.30 acres} \times 55\% = \textbf{0.08 lbs TN/day}$$

II. <u>Ponds, Grassed Waterways, Wildlife Habitat, Hay and Pasture Planting</u>

These practices are treated as a land use change from agricultural cropland to grassed waterways, or wildlife habitat. Thus, the acres that undergo change will receive a lower loading rate.

$$\text{Nutrient load reduction (lb/day)} = \left[\text{Agricultural loading rate (lbs/acre/day)} - \text{Grass loading rate (lbs/acre/day)}\right] \times \text{Acres of practices}$$

EX: TN reduction due to 36.90 acres of wildlife habitat in Red Clay watershed:

$$\text{TN load reduction (lb/day)} = \left[\text{0.019 lbs TN/acre/day} - \text{0.017 lbs TN/acre/day}\right] \times \text{36.90 acres} = \textbf{0.06 lbs TN/day}$$

III. <u>Filter Strips</u>

The Conservation Reserve Enhancement Program (CREP) practices such as filter strips are assumed to act as grassed buffers. Thus, the Workgroup assumed that for every one acre of land where these practices are employed, that two upland acres are treated. This approach is similar to the practice employed by the Chesapeake Bay Program (CBP, 1998). The efficiencies for nutrient load reductions are an average of the range presented by J.T. Sims and J.L. Campagnini (written communication, 2002). Thus, the agreed efficiencies are as follows:

Grassed buffers: TN-- 46% and TP-- 54%

For these BMPs, the actual acre of the practice will be treated as a land use conversion and the reduction efficiencies will be applied to two acres of affected upland for each acre of practice.

$$\text{Nutrient load reduction (lb/day)} = \left[\left(\text{Agricultural loading rate (lbs/acre/day)} - \text{Grass/Open loading rate (lbs/acre/day)}\right) \times \text{Acres of CREP practices}\right] + \left[\text{2 x Acres of CREP practices} \times \text{Agricultural loading rate (lbs/acre/day)} \times \text{Reduction efficiency (\%)}\right]$$

EX: TN reduction due to 728 acres of CREP filter strips in the Red Clay watershed:

$$\text{TN load reduction (lb/day)} = \left[\left(\text{0.019 lbs TN/acre/day} - \text{0.017 lbs TN/acre/day}\right) \times \text{728 Acres}\right] + \left[\text{2 x 728 Acres} \times \text{0.019 lbs TN/acre/day} \times 46\%\right]$$

$$= \textbf{13.81 lbs/acre/day}$$

III. Nutrient Management Plans

To reduce agriculture's impact on water quality, Delaware legislated a nutrient management program in 2002 to oversee nutrient applications within the State. In 2003, 20% of farmers applying nutrients to 10 acres or more or those who manage 8 or more animal units within the state were required by the Nutrient Management Act to create and submit a nutrient management plan (NMP) to the Nutrient Management Commission (NMC). Each year between 2004 and 2007, another 20% of eligible farmers were required to have NMPs, with 100% implementation by January 1, 2007. These plans are routinely updated and modified to meet the nutrient needs of the future cropping rotations and practices.

The Delaware Conservation Partnership (DCP) conducted a survey in July 2007, after the deadline requiring all eligible farm operations to have a plan, to evaluate nutrient management planning in the state. The DCP consists of the Delaware Conservation Districts, the Natural Resources Conservation Service, and the Delaware Department of Natural Resources and Environmental Control, and strives to work together to meet the needs of Delaware Farmers by providing cost-share programs, educational opportunities, and nutrient management planning services. The survey was designed to inform those programs by identifying gaps in information and education and opportunities to spend cost-share dollars more effectively. In short, the purpose of the project was to make nutrient management work better for farmers in Delaware.

The surveys were sent out to everyone who has been certified by the Nutrient Management Program- 2,034 people in all. The Delaware Conservation Partnership received 698 responses- about a 34% response rate. The following is the breakdown of responses among different sizes of farms:

1-10 acre farms – 9% response rate
11-99 acre farms – 29% response rate
100-499 acre farms – 25% response rate
500 + acre farms – 20% response rate
Animal only farms – 10% response rate

Responses varied only slightly among different farm sizes and types, with the exception of whether or not nutrient management provided an economic benefit to their farm. Larger farms and those whose plans were written by a private consultant were most likely to agree that nutrient management provides an economic benefit to their operation. Small farms, animal operations and those whose plan was written by someone on staff were least likely to agree.

The surveys indicated that fertilizer application rates have decreased the most among farmers who till at least 500 acres, while manure applications have decreased most among farmers who till between 11 and 99 acres. When fertilizer application rates are evaluated by county, Sussex farmers reduced the rate of N and P applications the most, Kent reduced N applications the least, whereas New Castle deceased P applications the least.

Table 5. Change in Fertilizer and Manure Application Rates Due to 2002 Nutrient Management Law				
<u>*County*</u>	<u>*Farm Acres*</u>	<u>*% Change in nitrogen fertilizer applications*</u>	<u>*% Change in phosphorus fertilizer applications*</u>	<u>*% Change in manure application*</u>
Kent	173,808	13.4	26.9	5.4
New Castle	66,981	16.0	20.1	13.6
Sussex	269,464	18.5	37.1	24.2
Weighted Average		16.7	1.4	19.9

The efficiencies based on the DCP survey can be compared to other estimates of nutrient management planning effectiveness. An Agricultural Workgroup was established to gather the best available science on nonpoint source pollution prevention for agricultural sources. The Workgroup operated off the basic assumption that if fewer nutrients are being applied to the land, fewer nutrients will be lost to Delaware's water bodies. From this premise, the Workgroup determined nutrient efficiencies for various agricultural best management practices including the effectiveness of nutrient management planning.

Initially, the Workgroup addressed the impact of nutrient management planning (NMP) in the Inland Bays and Nanticoke watersheds from a study by McGowan and Milliken (1992). This study listed the reductions associated with various management practices observed over a three year period, with a total of 103,736 lbs TN reduced by 2,328 acres under nutrient management planning. To determine a general NMP TN reduction, the Workgroup decided that the reductions and acreage associated with manure allowance and cover crops should be removed from further calculations since reductions for both of these items are determined separately and all NMPs will not include manure relocation. This subtraction gave a total of 1,224 acres of nutrient management planning and a load reduction of 70,136 lbs of TN, resulting in a reduction rate of 57.3 lbs/acre per 3-year planning cycle. McGowan and Milliken (1992) reported that the TN application rate prior to the introduction of NMPs was 280 lbs/acre per 3-year planning cycle, so NMPs produced a 20.5% reduction in TN. This estimate falls in the lower range reported by the State of Maryland (MDNR, 1996), which was 20-39% for nitrogen. The corresponding phosphorus range reported by the Maryland DNR was 9-30%. However, due to the absence of a report similar to the McGowan and Milliken study in Delaware for P, there is not enough information available to determine an appropriate reduction efficiency to apply to NMPs for phosphorus in these two watersheds.

In the Appoquinimink watershed, one representative farm within the watershed volunteered to allow the Workgroup to analyze the nutrient data they routinely gather. This particular farm tracks nutrient application rates to each crop field within a database that goes back to 1999, prior to the passing of the Nutrient Management Act. The data were separated into two groups, pre-Nutrient Management Plans (NMPs) (1999-2002) and post-NMPs (2003-2004), and entered into Statgraphics Software for statistical analysis. It was determined that there was a statistically significant difference between the mean application rates at the 95% confidence level for nitrogen. The average nitrogen application rate decreased by 12.4% from the pre-NMP level and this value will be taken as the NMP reduction efficiency; unfortunately, no reduction could be calculated for phosphorus from this data.

At the request of the NMC, Sims et al. (2008) conducted extensive nutrient mass balance calculations for the State for the years 1996 through 2006. They calculated both input/output and management–oriented mass balances for nitrogen and phosphorus. The Sims et al. (2008) approach included calculations for manure relocation and estimates of biological fixation of nitrogen by leguminous crop and clearly demonstrated that fewer nutrients are being applied to Delaware’s cropland.

DNREC Watershed Assessment Section (WAS) has worked with the NMC and the University of Delaware Cooperative Extension to determine the impact of the Nutrient Management Act on the amount of nutrients applied to Delaware’s agricultural fields. Using an input-output type analysis using fertilizer sales data and crop yields, WAS determined that on a state-wide basis, 47% less nitrogen and 62% less phosphorus has been applied to Delaware’s cropland. Both the WAS and Sims et al. (2008) approach produced similar results.

The DCP values, which are based on the reductions in nutrient applications actually reported by Delaware farmers, fall within the range of efficiencies determined by the numerous other methods and data sets discussed above. As a result, DNREC proposes to use the DCP efficiencies to estimate the reduction in nutrient application rates resulting from the promulgation of the Nutrient Management Law.

Using the TN and TP efficiencies and the agricultural loading rate reported earlier, the annual and daily load reductions due to these acres can be calculated as follows.

TN load reduction (lb/day)	=	205.40 acres under NMPs in Red Clay	x	Agriculture loading rate (0.019 lbs TN/acre/day)	x	Reduction efficiency (16%)	=	**0.62 lbs TN/day**

Overall Nutrient Load Reductions

The total nutrient reductions achieved by practices currently on the ground in the wastewater, stormwater, open space and agricultural sectors have been determined. In addition, the nutrient reductions possible from several potential future wastewater management policies and stormwater projects have also been estimated. These values are shown in Tables 6-9 along with the nutrient reductions required to meet the TMDL goals.

Table 6. Nutrient Reductions Achieved from Current and Potential Future BMPs in the Brandywine Watershed

	TN Reduced (lbs/day)	TP Reduced (lbs/day)
Wastewater	1.18	0.03
Stormwater	3.68	0.30
Agriculture	153.27	15.24
Open Space	5.84	0.61
Sub-total	**163.97**	**16.18**
Future Wastewater	30.04	1.05
Future Stormwater	1.10	0.09
Total	**195.12**	**17.32**
Required Reduction	**29.12**	**3.88**

Table 7. Nutrient Reductions Achieved from Current and Potential Future BMPs in the Christina Watershed

	TN Reduced (lbs/day)	TP Reduced (lbs/day)
Wastewater	3.01	0.09
Stormwater	20.19	2.50
Agriculture	0.64	0.04
Open Space	4.25	0.25
Sub-total	**28.09**	**2.87**
Future Wastewater	76.81	2.69
Future Stormwater	6.06	0.75
Total	**110.95**	**6.31**
Required Reduction	**108.11**	**4.70**

Table 8. Nutrient Reductions Achieved from Current and Potential Future BMPs in the Red Clay Watershed

	TN Reduced (lbs/day)	TP Reduced (lbs/day)
Wastewater	2.77	0.08
Stormwater	9.61	0.76
Agriculture	14.61	1.24
Open Space	0.00	0.08
Sub-total	**27.00**	**2.16**
Future Wastewater	70.80	2.48
Future Stormwater	2.88	0.23
Total	**100.68**	**4.87**
Required Reduction	**82.34**	**9.74**

Table 9. Nutrient Reductions Achieved from Current and Potential Future BMPs in the White Clay Watershed		
	TN Reduced (lbs/day)	**TP Reduced (lbs/day)**
Wastewater	3.28	0.09
Stormwater	38.10	2.13
Agriculture	25.11	1.87
Open Space	0.80	0.24
Sub-total	**67.28**	**4.34**
Future Wastewater	83.60	2.93
Future Stormwater	11.43	0.64
Total	**162.31**	**7.91**
Required Reduction	**123.97**	**24.76**

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